Mid-Frequency Propagation Modeling Using The Waveguide Invariant

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LONG-TERM GOALS

Random variability in shallow water will induce variability in a propagating acoustic field. The long-term goal of this research is to quantify how random variability in the ocean environment translates into random variability in the acoustic field and the associated signal processing algorithms.

OBJECTIVES

Coming from the Russian literature, the so-called waveguide invariant summarizes complicated interference effects that result from multipath propagation in the ocean [Petukhov, 2002]. Traditionally, the waveguide invariant has been viewed as a low-frequency phenomena applicable for incoherent processing of passive sonar data, but in recent years it has begun to be applied in the mid-frequency regime for coherent processing and active sonar [Rouseff and Zurk, 2011; Zurk and Rouseff, 2012]. These new applications in new frequency regimes render the waveguide invariant more sensitive to environmental variability. The objective in the current fiscal year has been to develop a model for horizontal array coherence in the presence of shallow water internal waves. The coherence length defines the maximum length array over which waveguide invariant-based processing can be used when processing coherently.

APPROACH

The approach is a mixture of data analysis, theoretical development, and numerical modeling. Dr. Dajun Tang of the University of Washington Applied Physics Laboratory (APL-UW) is a key individual in acquiring suitable acoustical and environmental data sets that can be used in the analysis. Dr. Lisa Zurk of Portland State University is a key individual in developing the invariant-based signal processing algorithms. Dr. Andrey Lunkov of the General Physics Institute, Moscow, has been a key individual in developing theoretical models for calculating array coherence. Dr. Lunkov received support for the collaboration from ONR-Global.

WORK COMPLETED

In the current fiscal year, a model for horizontal array coherence in the presence of linear shallow water internal waves was developed. The model ignores horizontal refraction and mode coupling, assumptions that should be reasonable up to ~1kHz. The key environmental input is the depth-

integrated energy in the internal wave field. A survey of shallow-water field measurements over the last two decades bounds the internal wave energy to be between 100 and 550 Joules/m^2. One possibly unique aspect to the model is that it avoids making the well-know, but sometimes dubious, Markov approximation [Gulin and Lysanov, 2008] that simplifies the assumed correlation function for the internal wave field. A second possibly unique aspect to the model is that it defers choosing a specific dispersion relationship for the internal waves until almost the last step in the calculation. In the present approach, the dispersion relationship can be site specific and based on local environmental conditions. The dispersion relationship affects both the spatial and temporal coherence of the acoustic field.

The work has been documented at an IEEE Oceans conference paper and in a refereed journal publication accepted for publication.

RESULTS

Calculations were made using environmental data collected during the ONR-supported SW06 Experiment [Tang *et al*. 2007]. Sound speed and buoyancy profiles representative of periods when transient nonlinear internal waves were absent were used. A detailed sensitivity study was performed to understand how the coherence length depended on relevant acoustic and environmental parameters: source/receiver positions, frequency, range, internal wave energy, seabed absorption, etc.

Figure 1 is a representative result. Shown is how the coherence length varies as a function of source depth for four different receiver depths. The different depths represent a receiver in the surface mixed layer (10 m), in the thermocline (18 m), below the thermocline (60 m), and on the bottom (79 m). The calculations were made at frequency 400 Hz and range 20km using as input parameters representative of the SW06 environment.

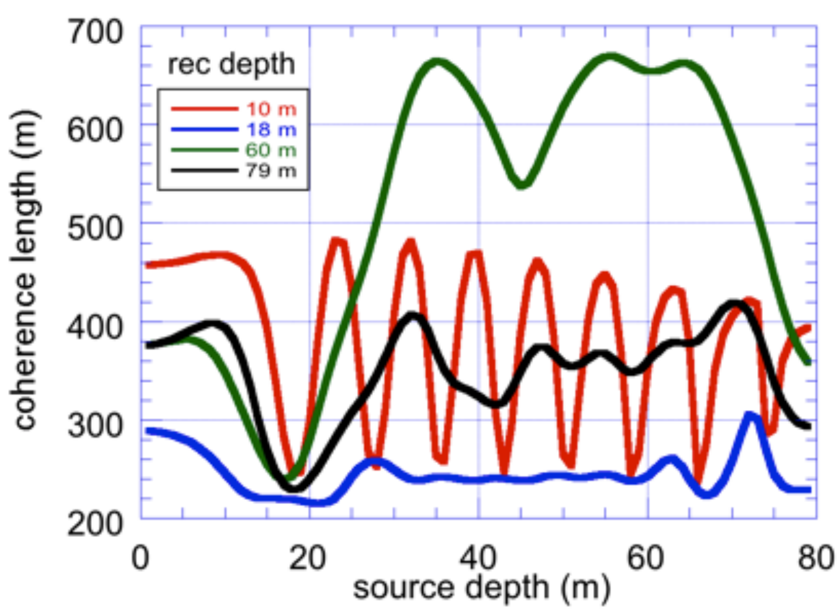

Figure 1. Effect of source depth on coherence length, various receiver depths for SW06 environment. Frequency 400 Hz, range 20 km, internal wave energy 400 J/m^2. The results show how the coherence length depends strongly on where the acoustic source and receiver are positioned relative to the thermocline.

The results show how the coherence length L_{coh} depends strongly on where both the source and the receiving array are positioned. The shallow array samples only the higher order, relatively oscillatory acoustic modes and the associated L_{coh} is oscillatory and strongly dependent on source depth. The array in the thermocline shows the lowest coherence. The array below the thermocline is strongly influenced by ducted acoustic modes and shows the highest coherence. The near-bottom array misses the ducted modes and has a nearly constant L_{coh}. An exception to the near-constant L_{coh} is when the source is in the thermocline. Consistent with what with investigators from the Naval Research Laboratory observed in the South China Sea, spatial coherence is low when the source or receiver are positioned at depths where there is a large sound speed gradient [Orr *et al.* 2004]. From the standpoint of "hiding," positioning the source in the thermocline produces the smallest L_{coh} regardless of the receiver depth. The results are reciprocal with the same L_{coh} calculated if the source and receiver positions are interchanged.

IMPACT/APPLICATIONS

Array coherence is fundamental to coherent array signal processing. The waveguide invariant is currently applied in practical sonar signal processing algorithms and extending its applicability to the mid-frequency regime is desirable.

RELATED PROJECTS

This project uses acoustical and environmental data collected in ONR-supported experiments like SW06, GulfEx and TREx. Collaboration with investigators from APL-UW in using these data sets will continue. Collaboration with investigators from Portland State University supported by the ONR Underwater Signal Processing will also continue.

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